Two new subterranean Parastenocarididae (Crustacea, Copepoda, Harpacticoida) from Western Australia

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Abstract – Two new species of the genus *Parastenocaris* Kessler, 1913 are described from Australian subterranean waters, both based upon males and females. *Parastenocaris eberhardi* sp. nov. has been found in two small caves in southwestern Western Australia. It belongs to the *"minuta"*-group of species, having five large spinules at base of the fourth leg endopod in male. The integumental window pattern of *P. eberhardi* is the same as for the first reported Australian representative (*P. solitaria*), which helps to establish its affinities too, since only females of the latter species were described. *Parastenocaris eberhardi* has a clear Eastern Gondwana connection, like many other Australian copepods of freshwater origins. *Parastenocaris kimberleyensis* sp. nov. is described from a single water-monitoring bore in the Kimberley district, northeastern Western Australia. It belongs to the *"brevipes"*-group of species, for which a key to world species is given. The present state of systematics within the family Parastenocarididae is briefly discussed.

INTRODUCTION

Until relatively recently the groundwater fauna of Australia was very poorly known (Marmonier *et al.* 1993), and that mostly from the investigation of cave faunas in the eastern portion of the continent (Thurgate *et al.* 2001a; 2001b). Western Australia has been considered to have poor prospects for supporting subterranean faunas, owing to the lack of water and low nutrient input from xeric plant communities (Moore 1964; Hamilton-Smith 1967; Barr 1973; Howarth 1980). Knowledge of this region, however, has developed substantially in the last decade, such that it is now recognized to include one of the world's most diverse and notable subterranean faunas (Holthuis 1960; Poore and Humphreys 1992, 1998; Wilson and Ponder 1992; Bartsch 1993; Humphreys 1993a, 1993b, 1993c, 2000, 2001; Bruce and Humphreys, 1993; Harvey *et al.* 1993; Aubrecht and Kozur 1995; Baltanas and Danielopol 1995; Yager and Humphreys 1996; Bradbury and Williams 1996a, 1996b, 1997a, 1997b; Harvey 1998; Knott and Halse 1999; Bradbury 2000, 2002; Watts and Humphreys 2000, 2001, 2003; Moore *et al.* 2001; Karanovic and Marmonier 2002, 2003). Recently, a number of stygal copepods have been described from ancient freshwater habitats (Pesce *et al.* 1996a; Pesce and De Laurentiis 1996; De Laurentiis *et al.* 1999, 2001; Karanovic 2003, 2004), as well as anchialine waters (Pesce *et al.* 1996b; Jaume and Humphreys 2001; Jaume *et al.* 2001; Karanovic *et al.* 2001; Lee and Huys 2002; Karanovic and Pesce 2002).

The family Parastenocarididae Chappuis, 1940 is almost exclusively freshwater in distribution (Boxshall and Jaume 2000) and has six well recognized genera: *Parastenocaris* Kessler, 1913; *Forficatocaris* Jakobi, 1969; *Paraforficatocaris* Jakobi, 1972; *Potamocaris* Dussart, 1979; *Murunducaris* Reid, 1994; and *Simplicaris* Galassi and De Laurentiis, 2004. Few species have been recorded from slightly brackish environments (Wells 1986), but none from marine littoral or meiofauna. Jakobi (1972) proposed a new system for the family by splitting it into 26 different genera, which was strongly criticized by Schminke (1976) and has not been adopted by Dussart and Defaye (1990) nor any other modern taxonomist. Although the phylogenetic relationships within the Parastenocarididae are still uncertain (Martínez Arbizu 1997), the system of eight phyletic groups proposed by Lang (1948) seems to be the most appropriate at this time, although it requires knowledge of males, and many species are still known only from females (more precisely, the *"proserpina"*-group was established by Kunz (1938) and Lang (1948) established the remaining seven groups). Lang's (1948) system was later supplemented by Noodt (1962, 1963, 1972), but with limited success. While one of Noodt's groups was consequently accepted and elevated to the generic level (*Forficatocaris*), others (although possibly phylogenetically correct) are morphologically hard to distinguish from previously known groups. However, all these groups are Neotropical and not related to the Australian Parastenocarididae. The genera *Forficatocaris, Paraforficatocaris, Potamocaris*

and *Murunducaris* contain only a few species and are exclusively Neotropical (Reid 1994). Currently, the genus *Parastenocaris* contains around 220 species and subspecies (Galassi and De Laurentiis 2004), although some of them are very inadequately described. Representatives of this genus are distributed over all continents, although, interestingly they have never been recorded in New Zealand (Huys and Boxshall 1991). Recently, Ranga Reddy (2001) reported the first Parastenocarididae from the Indian subcontinent (three new species of *Parastenocaris*), hardly surprising considering more than 20 species already known from Asia, including six of them from Sri Lanka (Enckell 1970). The taxonomic impediments surrounding the genus *Parastenocaris* was recently discussed by Galassi and De Laurentiis (2004), who also proposed a list of phylogenetically informative characters for this genus an the family as a whole. They also followed Reid's (1994) rejection of the Chappuis's (1933) description of the family as unavailable "until a cursory diagnosis was eventually supplied (Chappuis 1940)". Although this sounds taxonomically relatively just, it should be pointed out that Reid (1994), or any other author before 2000, did not expressly applied Article 13 of the then current edition of the ICZN Code and, therefore, is not completely satisfying Article 13.2.1 now (see ICZN 1999).

Parastenocaris solitaria Karanovic, 2004 is the only other representative of the family Parastenocarididae described from the Australian continent. It is known only from females, so its affinities could not be properly evaluated (Karanovic 2004). Schminke (1981) reported "four species belonging to three genera" of Parastenocarididae from Australia, but unfortunately they all remain undescribed and unnamed. In this paper two new Australian species of *Parastenocaris* are described, luckily based on both females and males. One of these is morphologically very similar to *P. solitaria*, which helps to establish the affinities of the latter, while the other belongs to a different group of species.

MATERIAL AND METHODS

The sample from the Kimberley district was collected by a haul-net (mesh size 250 micrometers) from a water monitoring bore. Haul-nets are simple plankton nets of different sizes suitable for the borehole, which can range from 30 to 180 mm in diameter. A weighted net was lowered down the borehole with a bottle screwed to its distal end, then hauled through the water column several times. The sample was sorted live under a dissecting microscope and the copepods picked out and fixed in 70% ethanol and assigned a field number (prefix

BES). Samples from the Margaret River caves were collected with a hand net, directly from the water body, or by washing tree roots and interstitial sand. Those samples were also assigned field numbers (prefix CW). Specimens were dissected and mounted on microscope slides in Faure's medium, which was prepared following the procedure discussed by Stock and Von Vaupel Klein (1996), and dissected appendages were then covered with a coverslip. For the urosome or the entire animal two human hairs were mounted between the slide and coverslip, so the parts could not be compressed. By manipulating the coverslip carefully by hand, the whole animal or a particular appendage could be positioned in different aspects, making possible the observation of morphological details. During examination water slowly evaporated, and appendages eventually remained in completely dry Faure's medium. All material has been deposited in the Western Australian Museum, Perth (WAM). Except for the abbreviations mentioned above and connected to the materials assignation, no others have been used. All drawings were prepared using a drawing tube attached to a Leica-DMLS brightfield compound microscope, with C-PLAN achromatic objectives. Morphological terminology follows Huys and Boxshall (1991), except for small differences in the spelling of some appendages (antennula, mandibula, maxillula instead of antennule, mandible, maxillule), as an attempt to standardize the terminology for homologue appendages in different groups of crustaceans.

SYSTEMATICS

Order Harpacticoida Sars, 1903

Family Parastenocarididae Chappuis, 1940

Genus *Parastenocaris* Kessler, 1913

Parastenocaris eberhardi sp. nov.
Figures 1–33

Material examined

Holotype
Female (WAM C28618), Western Australia, Margaret River Region, Strongs Cave, monitoring well, interstitial with tree roots, 6 July 2002, leg. S. Eberhard, 34°08'40"S 115°03'45"E (CW00265): dissected on 1 slide.

Allotype
Male (WAM C28619), Western Australia, Margaret River Region, Strongs Cave, monitoring well, interstitial with tree roots, 6 July 2002, leg. S. Eberhard, 34°08'40"S 115°03'45"E (CW00265): dissected on 1 slide.

Other paratypes

Western Australia, Margaret River Region, Strongs Cave, monitoring well, interstitial with tree roots, 6 July 2002, leg. S. Eberhard, 34°08'40"S 115°03'45"E (CW00265): 1 female in alcohol (WAM C28620).

Other material

Western Australia, Margaret River Region, Kudjal Yolgah Cave, root mat in a deep stream, 23 June 2002, leg. S. Eberhard, 34°05'55"S 115°02'22"E (CW00270): 1 female dissected on 1 slide (WAM C28621).

Description

Female (holotype)

Total body length, measured from tip of rostrum to posterior margin of caudal rami (excluding caudal setae), 374 µm. Preserved specimen colourless. Nauplius eye absent. Habitus (Figures 1 and 2) cylindrical and very slender, without demarcation between prosome and urosome; prosome/urosome ratio 0.8; greatest width very hard to locate. Body length/width ratio about 9.3; cephalothorax about 1.1 times as wide as double-somite. Free pedigerous somites without expansions laterally or dorsally. Integument not strongly chitinized, covered with minute pits (except cephalothorax, caudal rami and appendages), pattern becoming more dense towards posterior end of body; integumental windows on third and fourth urosomites (fourth and fifth urosomites, if second and third would not be fused into genital double-somite) laterally and on cephalothorax dorsally. Rostrum small, membranous, linguiform, reaching middle of first antennular segment, about as long as wide and not demarcated at base; with 2 dorsal sensilla. Cephalothorax about 1.9 times as long as wide; equaling 20% of total body length. Surface of dorsal shield covering cephalothorax with several very long sensilla and with large integumental window dorsally, inside which additional small area with even thinner integument visible. Tergites of 3 free pedigerous somites also with few large sensilla, but without integumental windows. Hyaline fringes of all somites smooth, except preanal somite, which hyaline fringe finely serrated both dorsally and ventrally. Genital double-somite (Figures 16 and 17) about as long as wide (ventral view), without any trace of subdivision, ornamented just with pair of median sensilla dorsally and 6 posterior sensilla (2 dorsal, 2 ventral and 2 lateral). Genital complex occupying anterior ventral half of genital double-somite. Genital apertures paired, each closed off by small, unarmed operculum derived from vestigial sixth leg. Median copulatory pore located anteriorly between genital apertures (Figure 16). Seminal

receptacles not discernable. Third urosomite ornamented with 6 long posterior sensilla (2 dorsal, 2 ventral and 2 lateral) and with 2 lateral cuticular windows (no ventral groups of large spinules at middle). Preanal somite without surface ornamentation, with 2 lateral cuticular windows similar to those on previous somite (Figures 16 and 17). Anal somite with pair of large dorsal sensilla and pair of lateral (1 on each side) cuticular pores in proximal half. Anal operculum (Figure 1) with almost straight posterior margin, smooth, not reaching posterior end of anal somite and representing 71% of somite's width. Anal sinus smooth.

Caudal rami (Figures 10, 11 and 16) relatively long, semicylindrical (with greatest width at 3/5 of ramus length), divergent, with space between them about twice width of ramus, and about 2.9 times as long as greatest width (ventral view); unornamented and armed with 7 armature elements (3 lateral, 1 dorsal and 3 apical). Dorsal seta relatively long, inserted slightly closer to inner margin at about 3/5 of ramus length, about 1.5 times as long as caudal ramus, biarticulate at base and smooth. Lateral setae thin and smooth, all shorter than ramus, inserted close to each other slightly posterior to dorsal seta. Inner apical seta smooth, slightly shorter than ramus. Middle apical seta strongest, without breaking plane, smooth, about 2.5 times as long as outer apical seta, and 0.3 times as long as whole body. Outer apical seta also without breaking plane, but pinnate along outer margin.

Antennula (Figure 3) 7-segmented, unornamented, approximately as long as cephalothorax, with broad aesthetasc on fourth segment not reaching beyond tip of appendage; more slender apical aesthetasc on seventh segment fused basally to apical seta; setal formula as follows: 0.4.4.1.1.0.9. Proximalmost seta on second segment unipinnate and articulating on basal part; all other setae smooth and without breaking plane or articulation. Length ratio of antennular segments, from proximal end, 1 : 3 : 1.3 : 1.4 : 0.7 : 0.8 : 1.4.

Antenna (Figure 4) short and robust, composed of coxa, allobasis, 1-segmented endopod, and 1-segmented exopod. Coxa small, unornamented. Allobasis about 2.8 times as long as wide, unarmed, and ornamented with 2 bunches of spinules on anterior surface. Endopod about 2.7 times as long as wide, with surface frill subdistally, ornamented with few long spinules along anterior surface, armed laterally with 2 spines and apically with 5 strong armature elements (2 of which geniculate). Exopod minute, cylindrical, about 3 times as long as wide, unornamented, armed with only 1 apical bipinnate seta, about 2.5 times as long as segment.

Mandibula (Figure 6) with narrow cutting edge on elongated coxa, armed with 3 coarse teeth
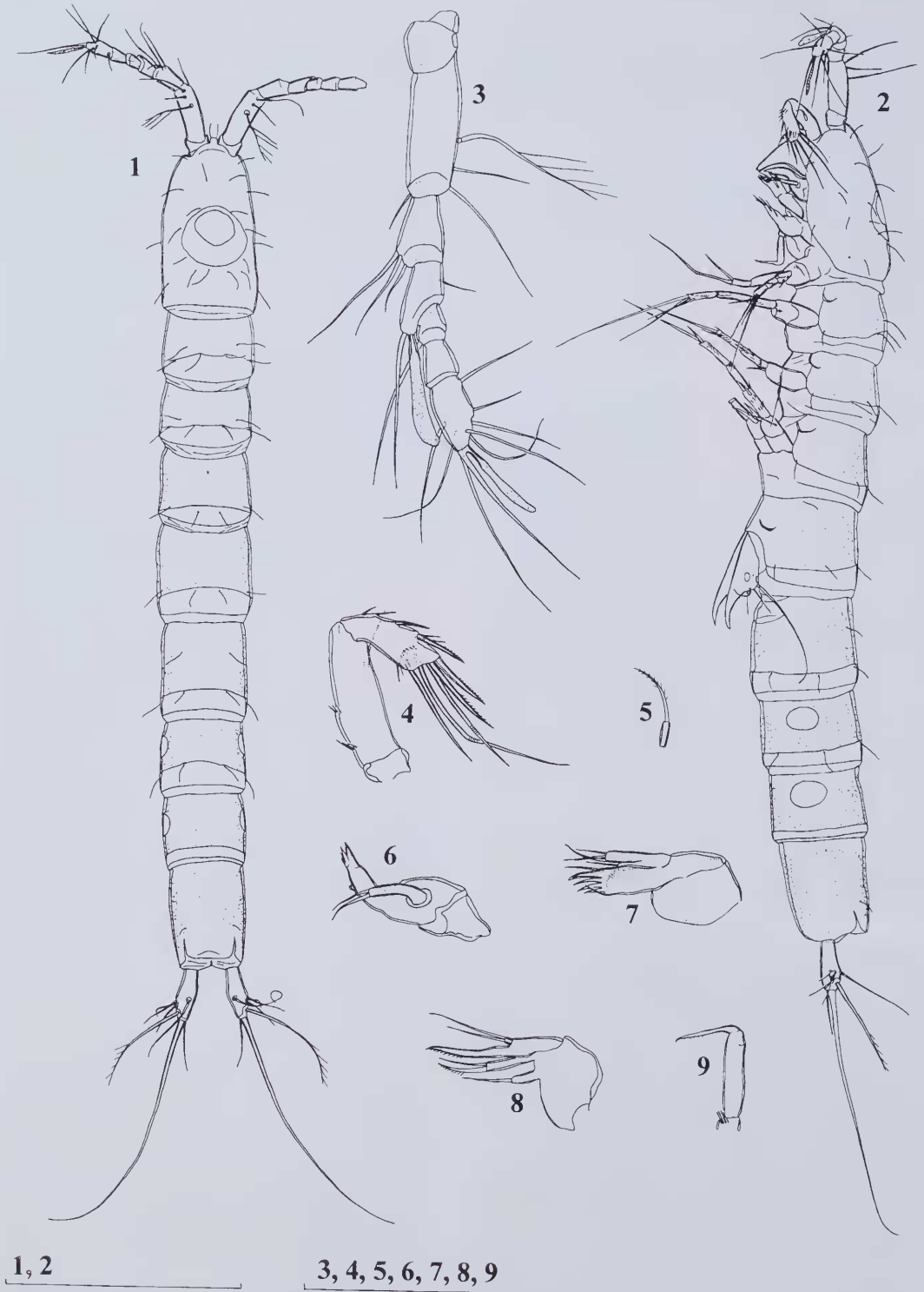
Figures 1–9 *Parastenocaris eberhardi* sp. nov., holotype (female): 1, habitus, dorsal view; 2, habitus, lateral view; 3, antennula; 4, antenna; 5, exopod of antenna; 6, mandibula; 7, maxillula; 8, maxilla; 9, maxilliped. Scales = 0.1 mm.
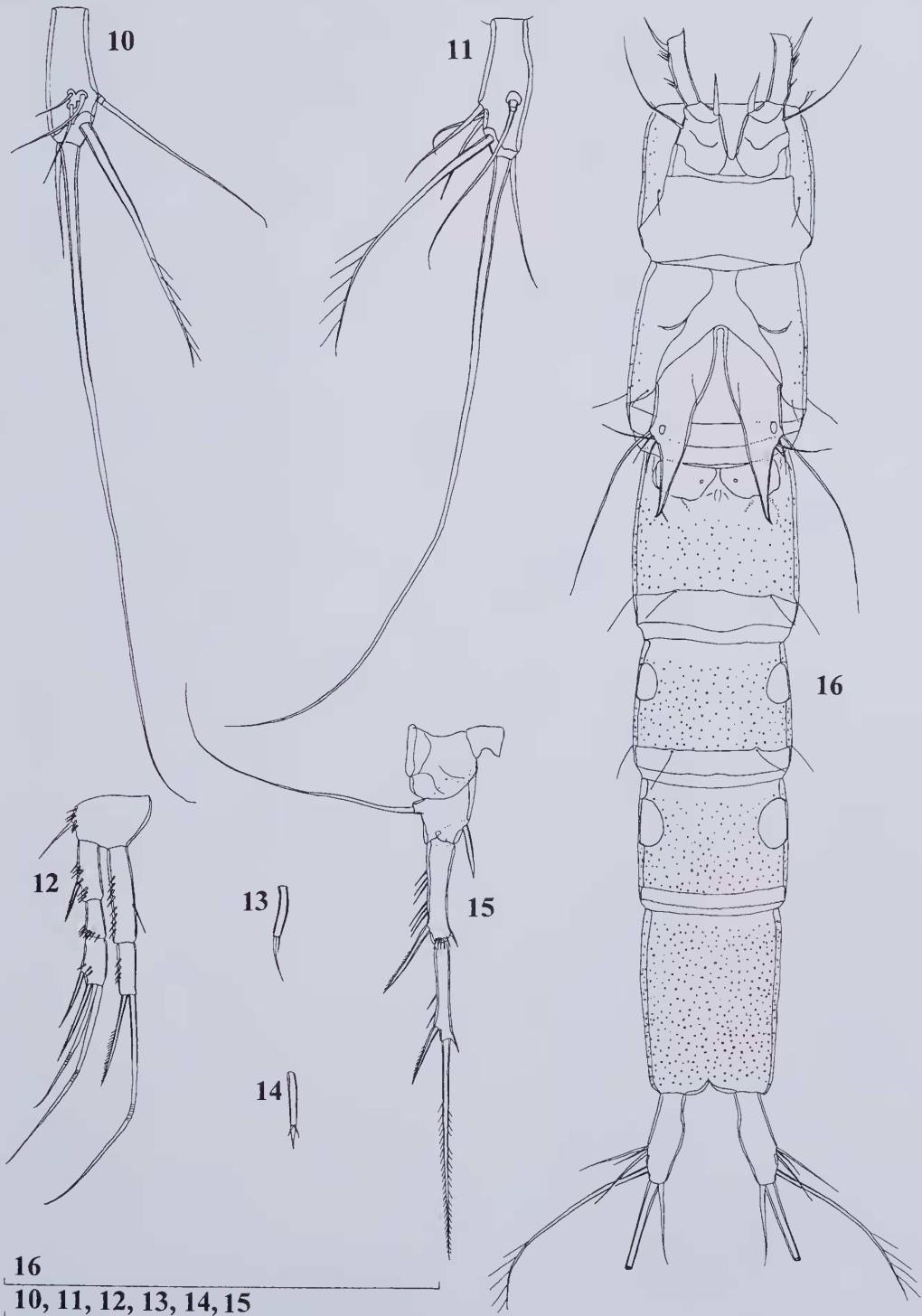
Figures 10–16   *Parastenocaris eberhardi* sp. nov., holotype (female): 10, left caudal ramus, lateral view; 11, left caudal ramus, dorsal view; 12, first swimming leg; 13, endopod of second swimming leg; 14, endopod of fourth swimming leg; 15, third swimming leg; 16, third free pedigerous somite and urosome, ventral view. Scales = 0.1 mm.

ventrally, 1 smooth seta dorsally, and several smaller teeth in between. Palp 1-segmented, cylindrical, about 4 times as long as wide, unornamented, and armed apically with 2 smooth subequal setae.

Maxillula (Figure 7) with large praecoxa, its arthrite rectangular, long, unornamented, and armed with 1 strong anterior surface setae, 1 lateral and 4 apical elements (probably 3 spines and 1 strong seta). Coxal endite small, armed with 2 smooth armature elements of about same length. Basis longer than coxal endite, armed with 3 naked setae apically. Endopod and exopod completely reduced.

Maxilla (Figure 8) with 2 endites on syncoxa; proximal one armed apically with only 1 bare seta; distal endite twice as long as proximal one, with naked seta and 1 pinnate spine. Basis drawn out into strong claw, without seta at base. Endopod represented by minute but distinct segment, with 2 bare subequal apical setae.

Maxilliped (Figure 9) with short syncoxa, ornamented with transverse row of long spinules; basis about 4 times as long as wide, unornamented and unarmed; endopod represented by distally pinnate curved claw, about 0.8 times as long as basis.

First swimming leg (Figure 12) with smooth coxa and intercoxal sclerite. Basis ornamented with few large spinules around insertation of outer spine. Exopod 3-segmented, armed with 1 outer spine on first segment and 4 armature elements on third segment (2 outer spines and 2 apical geniculate setae); ornamented with few large spinules along outer margin on all segments. Endopod 2-segmented, longer than exopod; first segment reaching slightly beyond distal margin of second exopodal segment, about 4.2 times as long as wide, armed with single smooth seta on inner margin, ornamented with large spinules along outer margin; second segment armed apically with long geniculate seta and much shorter spine.

Second swimming leg with smooth coxa, intercoxal sclerite and basis; basis armed with short outer spine. Exopod 3-segmented, ornamented with large spinules along outer margin, and with hyaline frills on each segment distally on inner side; first segment armed with single outer spine; second segment unarmed, third segment armed with 3 long armature elements (probably outer spine and 2 apical setae). Endopod (Figure 13) 1-segmented, slender, unornamented, reaching to middle of first exopodal segment, armed apically with 2 smooth thin setae; outer seta about 3 times as long as inner one.

Third swimming leg (Figure 15) also with smooth coxa, intercoxal sclerite and basis; basis armed with very long, smooth outer seta, about 1.4 times as long as exopod. Exopod 2-segmented, ornamented

with few large spinules along outer margin, both segments with hyaline frills distally on inner side; first segment armed with single outer spine; second segment armed with outer spine and apical strong seta. Endopod 1-segmented, unarmed and unornamented, in form of spiniform process, not reaching middle of first exopodal segment.

Fourth swimming leg with smooth coxa, intercoxal sclerite and basis; basis armed with long smooth outer seta. Exopod 3-segmented, ornamented with few large spinules along outer margin, and second and third segment with hyaline frills distally on inner side; first segment armed with single outer spine; second segment unarmed; third segment armed with outer spine and very long apical seta. Endopod (Figure 14) 1-segmented, in form of spiniform process, reaching 3/4 of first exopodal segment length; ancestral apical spine completely fused to somite, with 2 spinules at its ancestral distinction.

Fifth leg (Figure 18) simple triangular cuticular plate, ornamented with small cuticular pore basally and larger cuticular window; distal part protruding posteriorly as very long, outwardly curved, spiniform process, reaching almost middle of genital double-somite. Armature consists of very long outer basal seta and 3 additional small setae along outer margin.

Sixth leg (Figures 16 and 19) small cuticular plate, covering gonopore, ornamented with single cuticular pore and unarmed.

Male (allotype)
Body length, excluding caudal setae, 308 μm. Habitus, ornamentation of prosomal somites, colour and nauplius eye similar to female. Genital and first abdominal somite not fused; genital somite about twice as wide as long; first abdominal (third urosomal) somite ornamented with 2 ventrolateral bunches of 3–4 spinules at middle (Figure 25). Single large, completely formed, longitudinally-placed spermatophore (Figure 23) visible inside fifth pedigerous and genital somites. Cuticular windows, caudal rami (Figure 25), antenna, mandibula, maxillula, maxilla, maxilliped, first swimming leg (Figure 29) and fifth leg (Figure 25) similar to female.

Antennula (Figures 24 and 33) prehensile, 7-segmented, with very strong geniculation between fifth and sixth segment. Proximal anterior corner of fifth segment and distal anterior corner of sixth segment protruding like strong, spiniform processes, forming very powerful pincers. Proximal aesthetasc (in male of fifth segment instead on fourth) much wider than in female, while aesthetasc on apical segment similar to that of female. Setal formula as follows: 0.4.4.2.3.0.9.

Second swimming leg (Figure 30) without seta on outer margin of basis; segment ornamented with
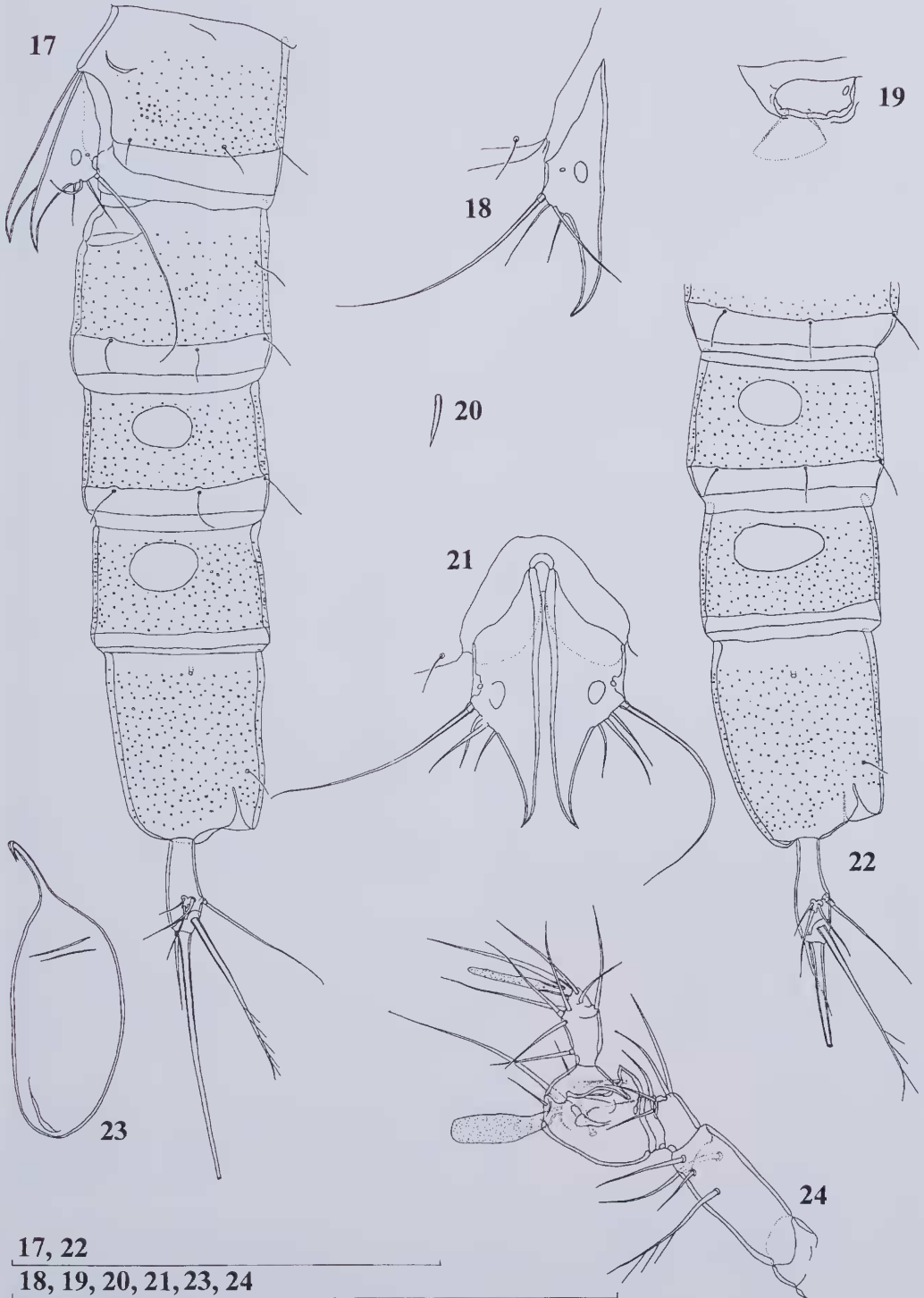
Figures 17–24   *Parastenocaris eberhardi* sp. nov., 17–19, holotype (female); 20–22, paratype (female); 23 and 24, allotype (male): 17, urosome, lateral view; 18, fifth leg; 19, sixth leg; 20, endopod of third swimming leg; 21, fifth legs; 22, abdomen, lateral view; 23, spermatophore; 24, antennula. Scales = 0.1 mm.
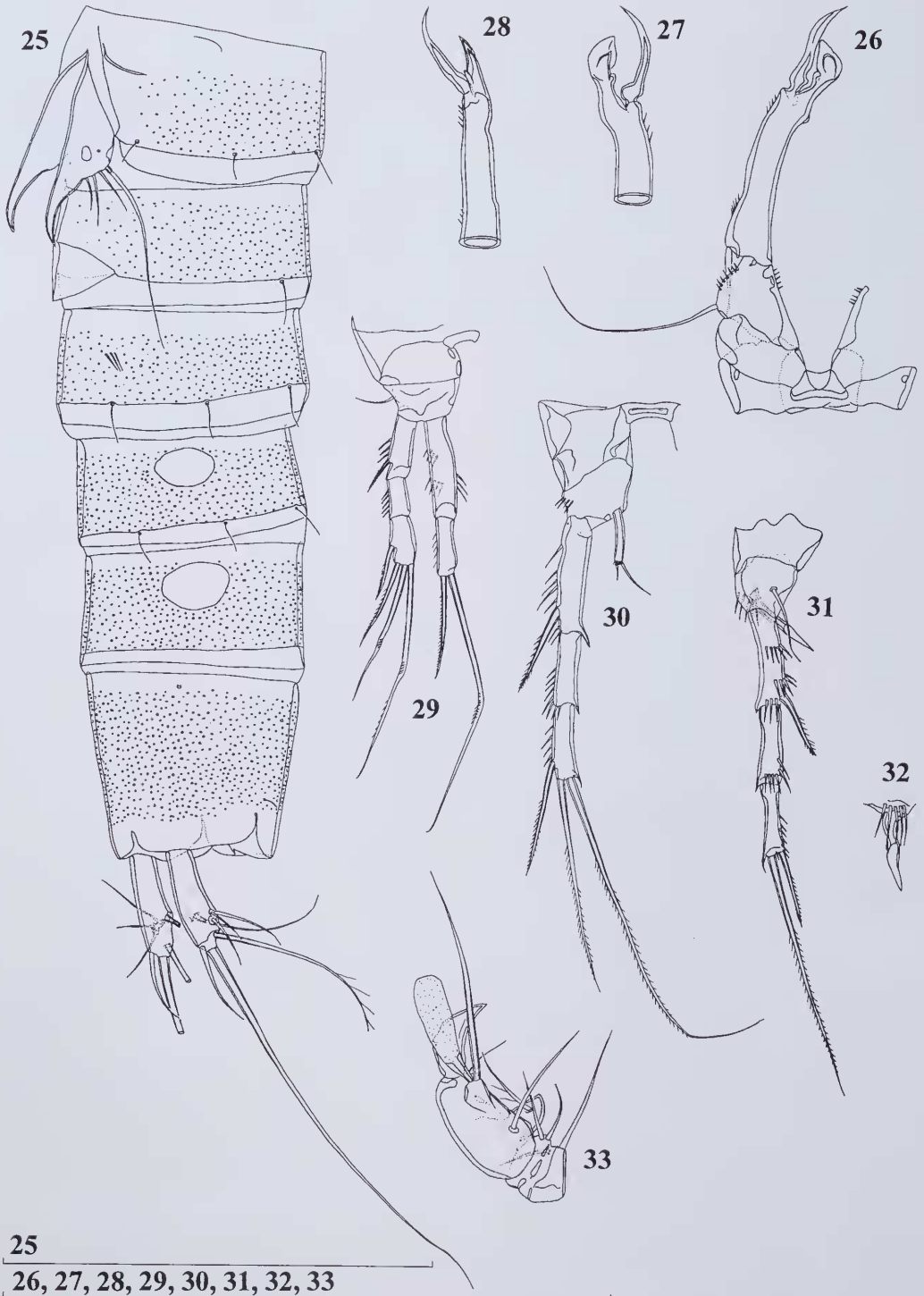
Figures 25–33 *Parastenocaris eberhardi* sp. nov., allotype (male): 25, urosome, semilateral view; 26, third swimming leg, anterior view; 27, distal part of third swimming leg, semilateral view; 28, distal part of third swimming leg, semiinterior view; 29, first swimming leg; 30, second swimming leg; 31, fourth swimming leg; 32, endopod of fourth swimming leg; 33, part of antennula. Scales = 0.1 mm.

several large spinules. Exopod and endopod similar to female.

Third swimming leg (Figures 26, 27 and 28) with smooth praecoxa, coxa and intercoxal sclerite. Basis robust, armed with long outer seta and ornamented with longitudinal row of spinules along distal part of inner margin and diagonal row of spinules close to outer margin. Endopod completely reduced. Exopod with both segments fused; ancestral proximal segment about 3.5 times as long as wide, curved inward, ornamented with 2 short rows of spinules along outer margin, armed subapically with large, smooth, curved and sharp spine, which reaching beyond end of whole exopod; ancestral distal segment (apophysis) small, terminating with outward curved tridimensional structure and forming pincers with armature element of first segment.

Fourth swimming leg (Figure 31) with exopod very similar to female. Endopod (Figure 32) also 1-segmented, but unornamented, curved and characteristically modified, with swollen and less sclerotized distal part; 5 large spinules at base of endopod, on inner side of basis.

Sixth leg (Fig 25) simple triangular plate, unarmed and unornamented; both sixth legs distinct at base and with close inner margins, but not fused.

Variability

Body lengths of females range from 339 μm to 383 μm (365 μm average; n=3); only one male was collected and studied. Cuticular windows on preanal somite of the paratype female (Figure 22) is larger than in holotype. The same female has somewhat curved endopod of the third swimming leg (Figure 20), as well as slightly shorter setae on the fifth leg (Figure 21).

Etymology

The species is named in honour of Mr Stefan Eberhard from the "Cave Works" (an ecotourism project of the Augusta Margaret River Tourism Association, Western Australia), who collected the material in which this species has been found.

Distribution

At present *Parastenocaris eberhardi* sp. nov. is known only from two caves in the Margaret River Region, southwestern Western Australia (Figure 63).

Parastenocaris kimberleyensis sp. nov.
Figures 34–63

Material examined

Holotype

Male (WAM C28624), Western Australia, Kimberley Region, Argyle Diamond Mine, monitoring bore 13S, 10 October 2002, leg. W.F. Humphreys and R. Webb, 16°43'18"S 128°24'02"E (BES: 9697.1): dissected on 2 slides.

Allotype

Female (WAM C28625), Western Australia, Kimberley Region, Argyle Diamond Mine, monitoring bore 13S, 10 October 2002, leg. W.F. Humphreys and R. Webb, 16°43'18"S 128°24'02"E (BES: 9697.1): dissected on 2 slides.

Other paratypes

Western Australia, Kimberley Region, Argyle Diamond Mine, monitoring bore 13S, 10 October 2002, leg. W.F. Humphreys and R. Webb, 16°43'18"S 128°24'02"E (BES: 9697.1): 2 males and 2 copepodids in alcohol (WAM C28626).

Topotype

Western Australia, Kimberley Region, Argyle Diamond Mine, monitoring bore 13S, 13 October 2002, leg. W.F. Humphreys and R. Webb, 16°43'18"S 128°24'02"E (BES: 9752): 1 male, dissected on 1 slide (WAM C28627).

Description

Male (holotype)

Total body length, measured from tip of rostrum to posterior margin of caudal rami (excluding caudal setae), 500 μm. Preserved specimen colourless. Nauplius eye absent. Habitus (Figure 34) cylindrical and very slender, without demarcation between prosome and urosome; prosome/urosome ratio 0.9; greatest width at posterior end of cephalothorax, but not very obvious. Body length/width ratio about 8.3; cephalothorax just slightly wider than genital somite. Free pedigerous somites without any expansions laterally or dorsally. Integument very weakly chitinized; integumental windows absent. Rostrum small, membranous, ovoid, reaching middle of first antennular segment, about as long as wide and not demarcated at base; with 2 dorsal sensilla. Cephalothorax about 1.6 times as long as wide; representing 20% of total body length. Surface of dorsal shield covering cephalothorax ornamented with only few small sensilla. Tergites of free pedigerous somites also ornamented with few small sensilla, except completely smooth first one. Hyaline fringes of all somites smooth. Genital somite ornamented with 2 small sensilla dorsally, about 1.5 times as wide as long, with single, large, completely formed, longitudinally-placed spermatophore (Figures 34 and 35) visible inside. Third and fourth urosomites ornamented with pair of dorsal and ventral spinules each. Fifth urosomal (preanal) somite
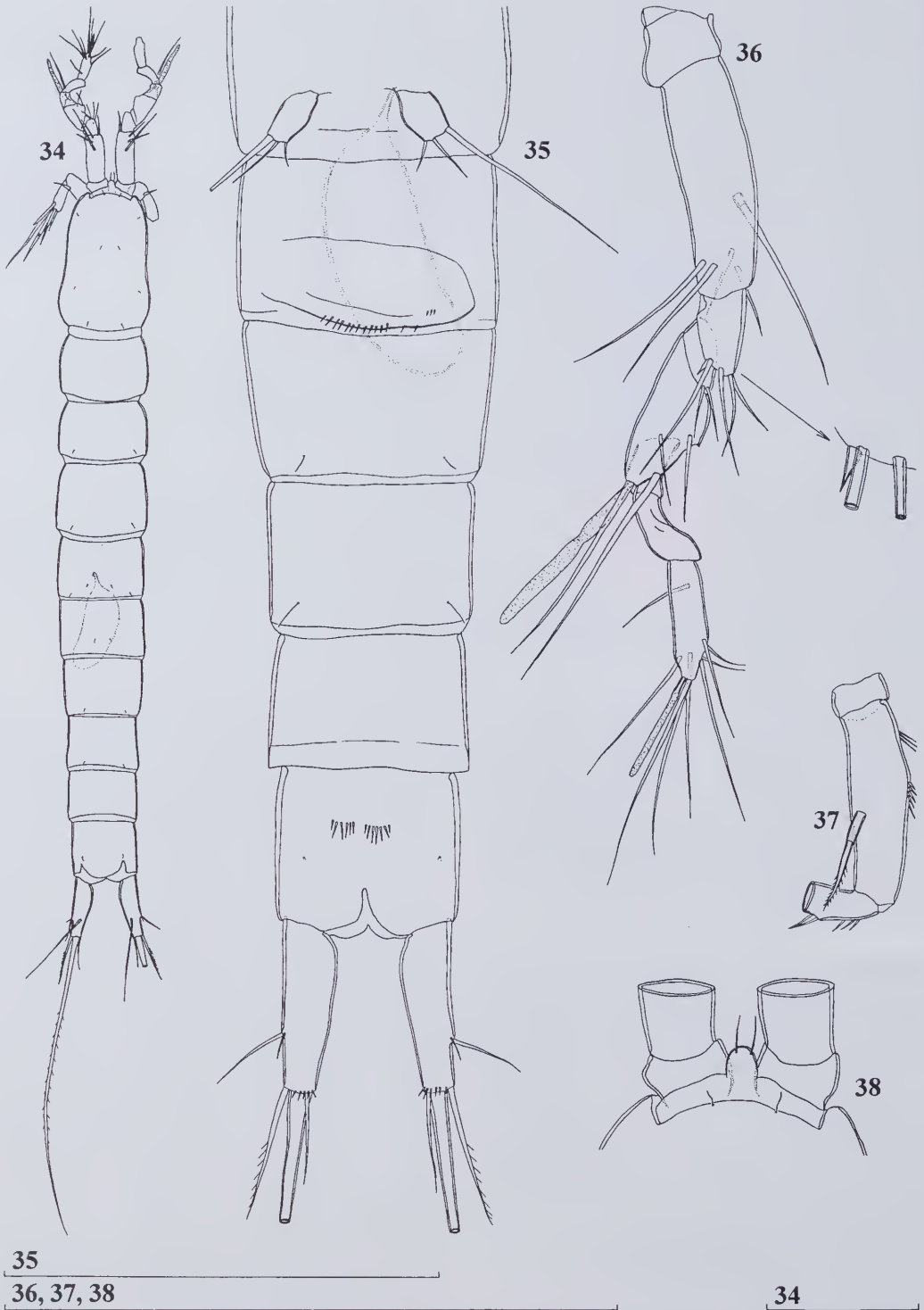
Figures 34–38 *Parastenocaris kimberleyensis* sp. nov., holotype (male): 34, habitus, dorsal view; 35, urosome, ventral view; 36, antennula, with enlarged detail of third segment armature; 37, antenna, without distal part of endopod; 38, rostral area, dorsal view. Scales = 0.1 mm.

without any visible ornamentation. Anal somite ornamented with pair of large dorsal sensilla, 2 ventral cuticular pores, and 2 short ventral rows of spinules at 1/3 of somite length. Anal operculum (Figure 41) strongly convex, smooth, not reaching posterior end of anal somite, representing 63% of somite's width. Anal sinus smooth.

Caudal rami (Figures 35, 41 and 42) long, cylindrical (slightly narrowing towards distal end), divergent, with space between them about 2 ramus width, and about 3.3 times as long as greatest width (ventral view); armed with 6 armature elements (2 lateral, 1 dorsal and 3 apical). Ornamentation consists of small cuticular pore laterally at anterior part. Dorsal seta relatively long, inserted somewhat closer to inner margin at about 2/3 of ramus length, about 1.3 times as long as caudal ramus, biarticulate at base and smooth. Lateral setae thin and smooth, inserted close to each other at 2/3 of ramus length. Proximal lateral seta placed more dorsally, about 3 times as long as distal one, and about 0.4 times as long as ramus. Inner apical seta small, smooth, about 0.5 times as long as ramus. Middle apical seta strongest, without breaking plane, bipinnate, about 6 times as long as outer apical seta and 0.4 times as long as whole body. Outer apical seta also without breaking plane, unipinnate along outer margin, about 0.8 times as long as ramus.

Antennula (Figures 36 and 44) 8-segmented, prehensile, not strongly geniculate, unornamented, approximately as long as cephalothorax. Broad aesthetasc on fourth segment reaching tip of appendage. Slender and short apical aesthetasc on eighth segment. Setal formula as follows: 0.5.5.2.4.0.0.9. Inner margin of fifth segment protruding into small spiniform process. One of setae on third segment very short, spiniform (Figure 36). All setae smooth and without breaking planes. Only 1 seta on second segment articulating on basal part.

Antenna (Figure 37) relatively slender and long, composed of coxa, allobasis, 1-segmented endopod, and 1-segmented exopod. Coxa small, unornamented. Allobasis about 3.3 times as long as wide, unarmed, and ornamented with 2 short rows of long spinules along anterior surface. Endopod about 2.8 times as long as wide, with surface frill subdistally, ornamented with few large spinules along anterior surface, armed laterally with 2 spines and apically with 5 strong armature elements (2 of which geniculate). Exopod minute, cylindrical, about 3 times as long as wide, unornamented, armed with only 1 bipinnate apical seta, about 2.3 times as long as segment.

Mandibula (Figure 39) with narrow cutting edge on elongated coxa, armed with 3 coarse teeth ventrally, 1 smooth seta dorsally, and several smaller teeth in between. Palp 1-segmented, cylindrical, about 3 times as long as wide,

unornamented, and armed apically with 2 smooth and subequal setae.

Maxillula (Figure 43) with relatively small praecoxa, arthrite of which rectangular, long, unornamented, and armed with 1 strong anterior surface setae, and 4 apical elements (probably 3 spines and 1 strong seta). Coxal endite armed with 1 smooth armature element apically, which about 1.5 times as long as endite. Basis longer than coxal endite, armed with 3 naked setae apically. Endopod and exopod completely reduced.

Maxilla (Figure 40) with 2 endites on syncoxa; proximal one armed apically with only 1 bipinnate seta; distal endite twice as long as proximal one, armed apically with 2 naked and 1 unipinnate setae. Basis fused basally with syncoxa, drawn out into strong claw, without seta at base. Endopod represented by minute but distinct segment, armed with 2 bare subequal apical setae.

Maxilliped (Figure 45) with unornamented short syncoxa; basis about 3 times as long as wide, unornamented and unarmed; endopod represented by short curved claw, which ornamented with row of spinules along concave side distally, about 0.7 times as long as basis.

First swimming leg (Figure 46) with smooth coxa and intercoxal sclerite. Basis ornamented with few large spinules around insertation of outer spine. Exopod 3-segmented, armed with 1 outer spine on first segment and 4 armature elements on third segment (2 outer spines and 2 apical geniculate setae); ornamented with few large spinules along outer margin on all segments. Endopod 2-segmented, somewhat longer than exopod; first segment reaching slightly beyond distal margin of second exopodal segment, about 3.4 times as long as wide, unarmed, ornamented with few large spinules along outer margin and 1 long row of large spinules along inner margin; second segment armed apically with long geniculate seta and much shorter spine.

Second swimming leg (Figure 47) with smooth coxa and intercoxal sclerite; basis unarmed, ornamented with row of large spinules on outer margin . Exopod 3-segmented, ornamented with large spinules along outer margin, and with hyaline frills on each segment distally on inner side; first segment armed with single outer spine; second segment unarmed; third segment armed with 3 long armature elements (probably outer spine and 2 apical setae), innermost one about 1.3 times as long as exopod. Endopod 1-segmented, linguiform, reaching to middle of first exopodal segment, ornamented with several spinules along apical margin, armed apically with 1 smooth seta, which about 1.5 times as long as segment.

Third swimming leg (Figure 48) with smooth praecoxa, coxa and intercoxal sclerite. Basis robust, armed with long outer seta and ornamented with
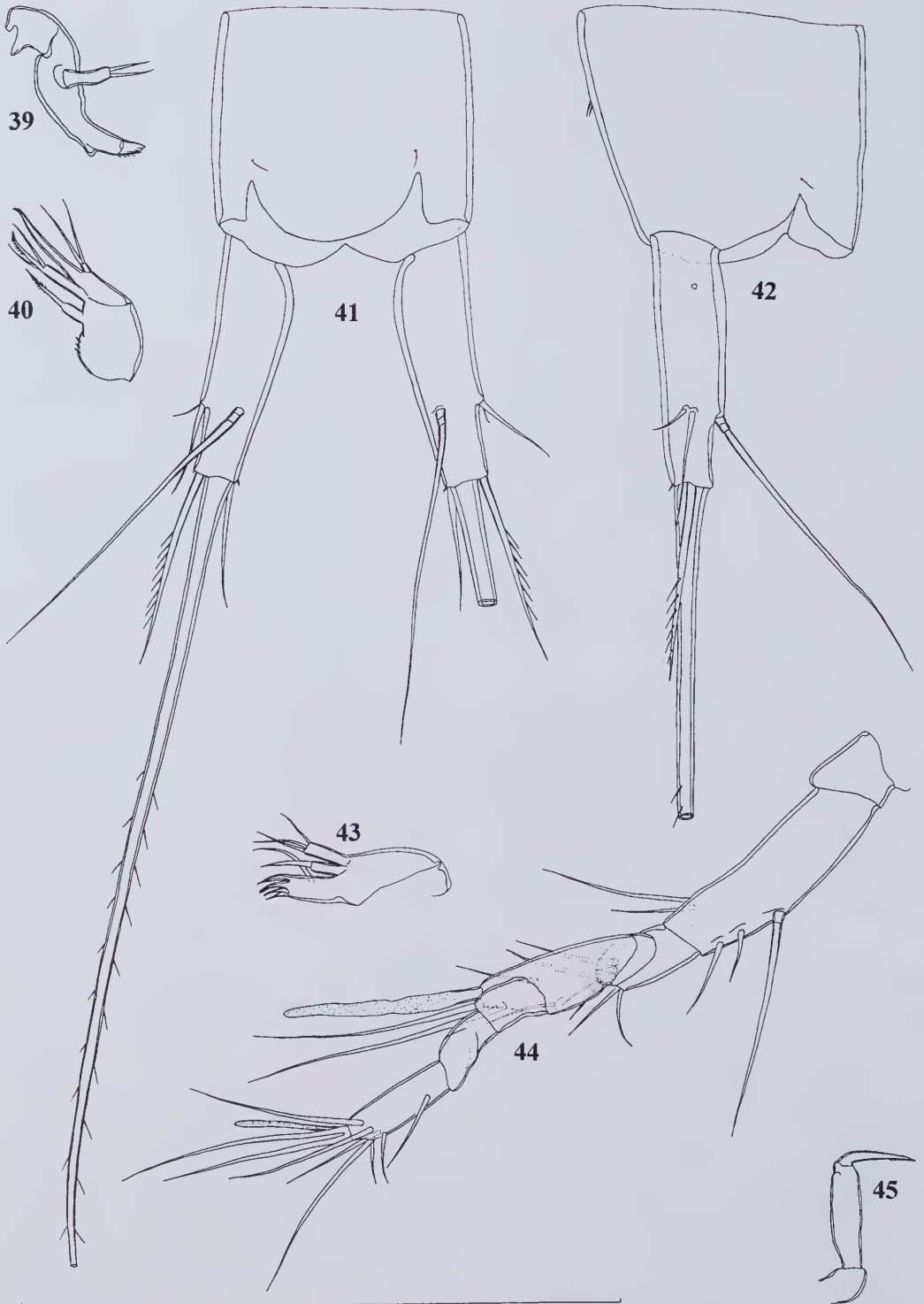
Figures 39–45 *Parastenocaris kimberleyensis* sp. nov., holotype (male): 39, mandibula; 40, maxilla; 41, anal somite and caudal rami, dorsal view; 42, anal somite and left caudal ramus, lateral view; 43, maxillula; 44, antennula; 45, maxilliped. Scale = 0.1 mm.
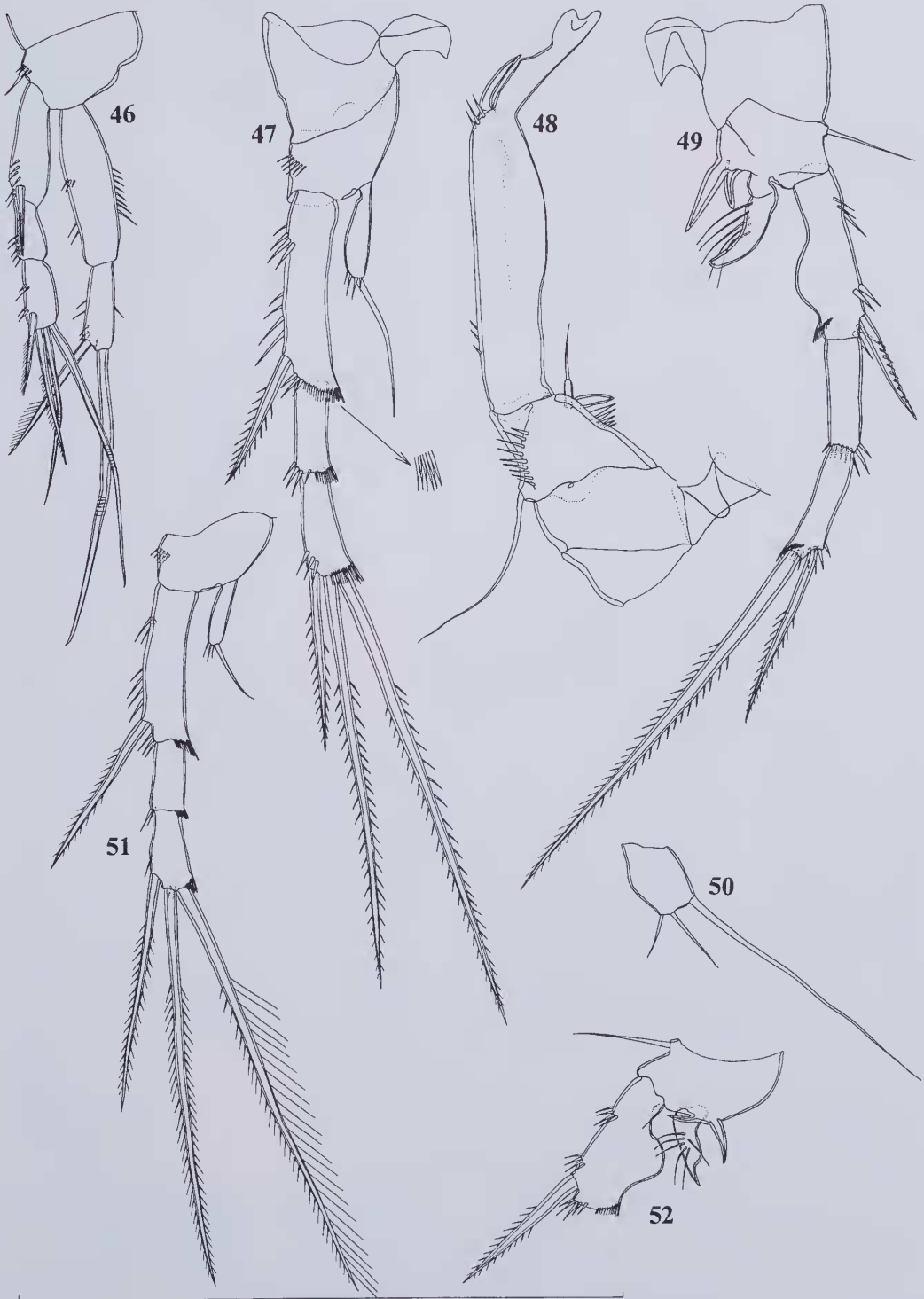
Figures 46–52 *Parastenocaris kimberleyensis* sp. nov., 46–50, holotype (male); 51 and 52, topotype (male): 46, first swimming leg; 47, second swimming leg; 48, third swimming leg; 49, fourth swimming leg; 50, fifth leg; 51, second swimming leg; 52, basis, endopod and first exopodal segment of fourth swimming leg. Scale = 0.1 mm.

longitudinal row of very large spinules along distal part of inner margin (distalmost strongest) and diagonal row of spinules close to outer margin. Endopod minute, 1-segmented, smaller than largest spinule on inner margin, unornamented and armed apically with smooth seta, which twice as long as segment. Exopod with both segments fused; ancestral proximal segment about 4 times as long as wide, somewhat swollen at distal part of inner margin, armed subapically with strong, short, smooth and curved spine, which reaching middle of apophysis; ancestral distal segment (apophysis) much smaller, oriented inward, unarmed and unornamented, terminating in U-shaped thin chitinous structure.

Fourth swimming leg (Figure 49) with smooth coxa, intercoxal sclerite and basis; basis armed with slender and smooth outer seta, inner-distal corner of basis produced into 2 large, heavily sclerotized claws, longer one almost as long as endopod. Exopod 3-segmented, ornamented with few large spinules along outer margin, and first and third segment with hyaline frills distally on inner side; first segment with swollen distal part of inner margin, armed with single outer spine; second segment unarmed; third segment armed with outer spine and very long and strong apical seta. Endopod 1-segmented, about 0.6 times as long as first exopodal segment, claw-like, curved inwards, unarmed and ornamented with longitudinal row of very long and slender spinules. Endopod and basal claws resembling powerful pincers.

Fifth leg (Figure 50) simple semitrapezoidal cuticular plate, unornamented and armed with 3 smooth setae along distal margin; outermost seta (ancestral basal one) longest, about 4 times longer than median one (which slightly shorter than plate) and about 6.5 times as long as innermost seta. Fifth legs distinct at base (Figure 35) with space between them of about 2 legs width.

Sixth legs (Figure 35) completely fused, forming single large operculum covering gonopore, which represents 80% of genital somite width, ornamented with transverse row of spinules along posterior margin and unarmed.

Female (allotype)

Body length, excluding caudal setae, 473 μm. Habitus, ornamentation of prosomal somites, colour and nauplius eye similar to male. Genital double-somite (Figures 63) about as long as wide (ventral view), without any trace of subdivision, ornamented only with 6 posterior sensilla (2 dorsal, 2 ventral and 2 lateral). Genital complex (Figure 58) occupying anterior ventral half of genital double-somite; genital apertures paired, each closed off by small, unarmed operculum derived from vestigial sixth leg; median copulatory pore located anteriorly between genital apertures; seminal receptacles

trapezoidal, small; copulatory duct not clearly visible inside somite. Caudal ramus (Figure 62), antenna (Figure 61), mandibula, maxillula, maxilla, maxilliped, first swimming leg (Figure 53) and second swimming leg (Figure 55) similar to male.

Antennula (Figure 56) 7-segmented, unornamented, approximately as long as cephalothorax, with broad aesthetasc on fourth segment, reaching middle of seventh segment, and more slender apical aesthetasc on seventh segment, which fused basally to apical seta; setal formula as follows: 0.5.5.2.1.0.9. Proximalmost seta on second segment and 1 seta on seventh segment articulating on basal part; all setae smooth and without breaking plane. Length ratio of antennular segments, from proximal end, 1 : 2.6 : 1.5 : 1.6 : 0.8 : 0.9 : 1.5.

Third swimming leg (Figure 54) with smooth intercoxal sclerite; coxa and basis ornamented with row of spinules near outer margin; basis armed with long and smooth outer seta, which about 0.7 times as long as exopod. Exopod 2-segmented, ornamented with large spinules along outer margin, both segments with hyaline frills distally on inner side; first segment armed with single outer spine; second segment armed with outer spine and apical strong seta. Endopod 1-segmented, with ancestral apical spine completely fused to segment, but still bipinnate; reaching 2/3 of first exopodal segment.

Fourth swimming leg (Figures 57 and 59) with first exopodal segment with inner margin straight and without spiniform processes on basis. Endopod 1-segmented, with ancestral apical spine fused to segment, with 3 large spinules at its base and unipinnate along inner margin. Other details similar to male.

Fifth leg (Figures 60 and 63) bilobate simple cuticular plate, ornamented with cuticular pore at base of outer (basal) lobe and with ring of spinules around acute extension of inner (endopodal) lobe. Basal lobe armed with long basal seta and small spine (or maybe spinule); inner lobe armed with two smooth and much shorter setae on outer margin (probably ancestral exopodal armature). Fifth legs separated medially, space between them less than one leg width.

Sixth leg (Figure 58) small cuticular plate, covering gonopore, unornamented and unarmed.

Variability

Body lengths of males range from 408 μm to 500 μm (467 μm average; n=4); only one female was collected and studied. Topotype male with comparatively longer spines on second swimming leg (Figure 51) and with smaller basal processes on fourth swimming leg (Figure 52), although they are drown in slightly different positions than those in the holotype. No other form of variability was observed.
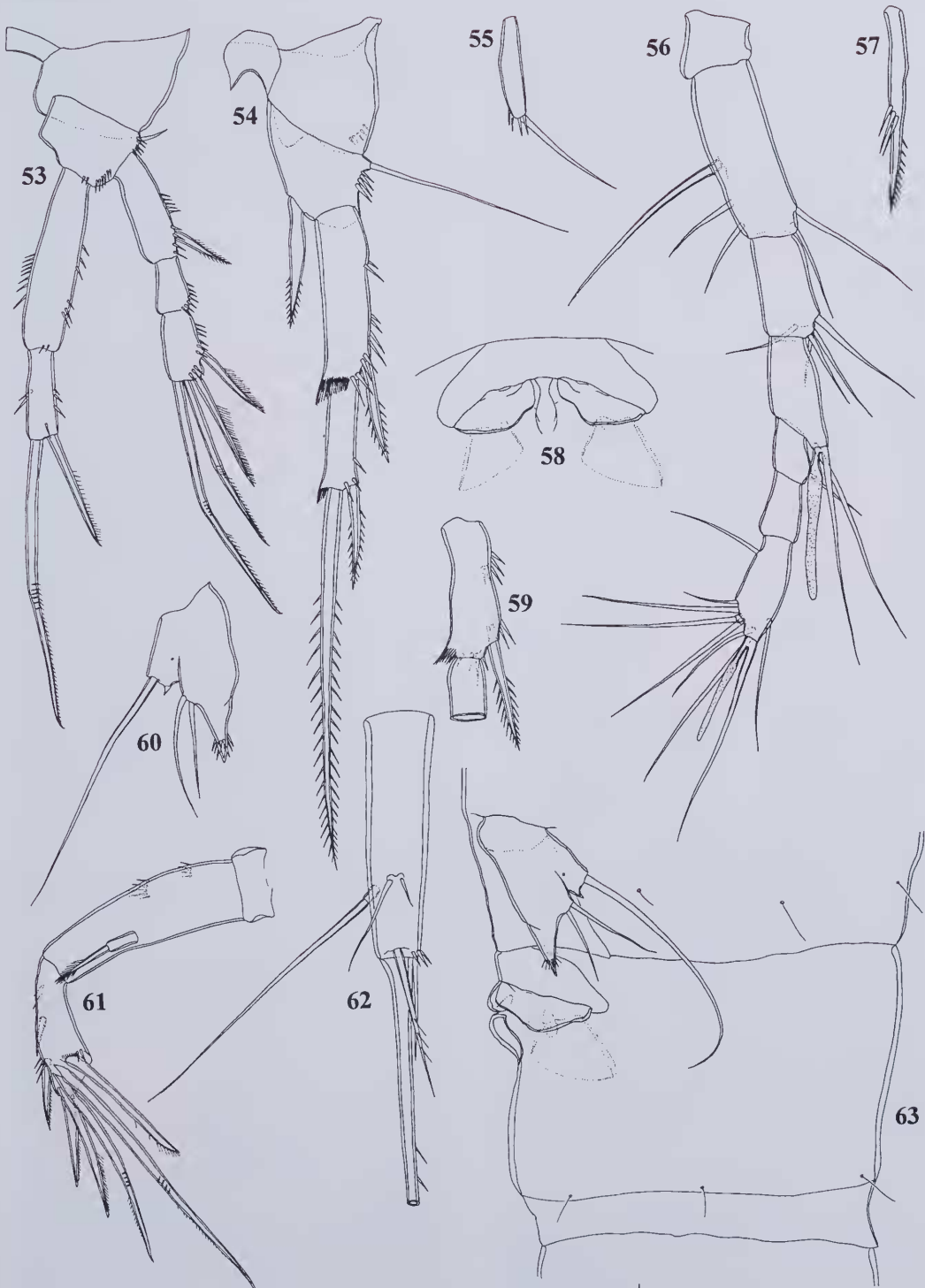
Figures 53–63 *Parastenocaris kimberleyensis* sp. nov., allotype (female): 53, first swimming leg; 54, third swimming leg; 55, endopod of second swimming leg; 56, antennula; 57, endopod of fourth swimming leg; 58, genital area, ventral view; 59, first exopodal segment of fourth swimming leg; 60, fifth leg; 61, antenna; 62, right caudal ramus, lateral view; 63, fifth pedigerous and genital double-somite, lateral view. Scale = 0.1 mm.

Figure 64   Distribution of the Australian Parastenocarididae: A, *Parastenocaris kimberleyensis* sp. nov.; B, *Parastenocaris solitaria* Karanovic, 2004; C, *Parastenocaris eberhardi* sp. nov.

Etymology

The species is named after the Kimberley Region, where it was collected.

Distribution

Parastenocaris kimberleyensis sp. nov. is so far known from a single monitoring bore in the Kimberley district, northeastern Western Australia (Figure 64).

DISCUSSION

Of the 224 or so described species and subspecies (together with the two new species described above) of the genus *Parastenocaris*, 18 (8%) are still known only from females, including the first Australian representative *P. solitaria* Karanovic, 2004. This, in conjunction with the high level of convergence in subterranean interstitial habitats,

makes phylogenetic analyses of this genus very difficult. Furthermore, some recent publications have added unnecessary confusion in this field. For instance Martinez Arbizu (1997) assigned his new species *P. hispanica* to the "*fontinalis*"-group. Moreover he analyzed the "phylogenetic relationships within the *fontinalis*-group", but considered only five species and subspecies, despite the fact that the "*fontinalis*"-group contains more than 60 taxa. However, based on the Lang's (1948) classification, *P. hispanica* is an obvious member of the "*proserpina*"-group. Large harpacticoid genera usually accumulate numerous synonyms during the course of their taxonomic history, and the genus *Parastenocaris* is certainly no exception; for example Reid (1995) established at least three new synonyms of *P. brevipes* Kessler, 1913. Sexual dimorphism and even polymorphism in caudal rami shape (Schminke 1991) is another phenomenon of this

genus which could contribute to further discoveries of new synonyms, but it is clear that the present number of species is only a small fraction of the total number to be expected (Reid 1982; Boxshall and Jaume 2000). Typical *Parastenocaris* habitats are only fragmentarily investigated on most continents, including Australia (Karanovic 2004). Future genetic investigations of similar morphological forms (considered now as one species) may even double the final number of species. So, even an estimation of 1000 or more species does not sound impossible (although it is only a speculation). However, the number of different phylogenetic lineages in the genus is limited to around a dozen (depending on how we treat some of the South American groups established by Noodt (1962, 1963, 1972)), indicating a very slow rate of evolution in this genus. Thus the assumption made by Boxshall and Jaume (2000) "that tectonic events have shaped modern distributions more than subsequent dispersal events" sounds so acceptable for *Parastenocaris*. Even the two Australian species described in this paper are not some bizarre creatures, but fit well into two existing groups of species originally defined by Lang (1948).

Parastenocaris eberhardi belongs to the "*minuta*"-group of species, the fourth leg basis having five large spinules around the base of the endopod in male. Although this group was originally defined by Lang (1948) to have "Einwärts von Enp.P4 Männchen sitzen 2–4 Borsten", this diagnosis was slightly emended by Karanovic and Bobic (1998) to include those species with only one inner basal spinule around the endopod. Also some species with more than four basal spinules have been described and assigned to the "*minuta*"-group: *P. arenicola* Chappuis, 1954 from Madagascar; *P. cornuta* Chappuis, 1955 from Lake Tanganyika; *P. forficulata* Chappuis, 1952 from Madagascar; *P. lusitanica* Noodt and Galhano, 1969 from Portugal; *P. madagascarensis* Chappuis, 1952 from Madagascar; *P. marlieri* Chappuis, 1955 from Lake Tanganyika; *P. oligoalina* Cottarelli, Bruno and Venanzetti, 1995 from Sardinia; and even in some populations of *P. vicesima* Klie, 1935 from Helgoland (Kiefer, 1960), which Lang (1948) had previously included in the "*minuta*"-group. Galassi and De Laurentiis (2004) were probably unaware of this fact, since they did not include *Parastenocaris serbica* Karanovic and Bobic, 1998 into their list of the "*minuta*"-group, nor the abovementioned *P. arenicola*, *P. forficulata*, *P. lusitanica*, *P. madagascarensis* and *P. marlieri*, although they included *P. cornuta* and *P. oligoalina*. However, I do agree with their conclusion that "the evidence already available strongly suggest polyphyletic origin of the *minuta*-group", a constatation nicely demonstrated by separating a new genus *Simplicaris*.

Parastenocaris eberhardi has the same combination of a "double" integumental window on the cephalothorax and paired lateral windows on the third and fourth (preanal) urosomites in female as *Parastenocaris solitaria* Karanovic, 2004, a species described also from Western Australia, but almost 800 km NNE from the former species (Figure 64). Because of the occurrence of integumental windows in distantly related taxa, as well as of similar structures in several other crustacean groups other than copepods, Lang (1948) stated that they have no phylogenetic significance. However, within the Harpacticoida at the alpha-taxonomic level their form and location on the body are constant within species, and have been useful in species discrimination in the Canthocamptidae (Hamond 1987; Por and Hadel 1986; Hosfeld 1999). Although it is reasonable to assume that *P. solitaria* also belongs to the "*minuta*"-group, its position cannot be verified woithout males. Females of *P. eberhardi* can be distinguished from those of *P. solitaria* by the following 13 characters: cuticular pits present; sensilla much longer; short rows of ventrolateral spinules on the third urosomite absent; anal somite longer; caudal rami shorter and less cylindrical; caudal rami armed with three lateral setae instead of two; innermost apical setae on caudal rami much longer; allobasis of antenna shorter; maxillula with three armature elements on coxal endite instead of two; distal endite of maxilla not reduced; endopod of fourth swimming leg ornamented with two spinules; fifth leg with somewhat shorter distal spiniform process; and cuticular window on fifth leg present (see Karanovic 2004). Actually, the cuticular window on the fifth leg in both sexes of *P. eberhardi* is something not previously recorded in the genus *Parastenocaris*, except perhaps in *P. pasquinii* Cottarelli, 1972 (see Bruno and Cottarelli 1998, figure 11F), but these two species differ remarkably from each other. The new Australian species can be easily distinguished from its congeners also by the characteristic shape of the third leg in male, which is somewhat similar only to that of *P. madagascarensis* from Madagascar and *P. aethiopica* Cottarelli and Bruno, 1995 from Ethiopia (see Chappuis 1952; Cottarelli and Bruno 1995). These two species seem to be most closely related to *P. eberhardi* and *P. solitaria*, and they all have the same pattern of integumental windows on the urosomites. However, they can be easily distinguished from *P. eberhardi* by a number of characters, including caudal rami shape, male fourth leg shape of endopod and third legs endopods not completely reduced. Paired lateral integumental windows on the third and fourth urosomites in females (and/or on the fourth and fifth in males) have also been described for the following three species: *P. arenosa* Fryer, 1956 from sandy beaches of Lake Nyasa; *P. forficulata*

Chappuis, 1952 from Madagascar; and *P. quollensis* Cottarelli and Bruno, 1995 from Ethiopia. This character should be considered in all future phylogenetic analyses of *Parastenocaris*, since it shows a clear Eastern Gondwana connection for the two Australian species, as well as many other Australian copepods with freshwater origins (see Karanovic 2003, 2004). Conversly, the cephalothoracic integumental window has no phylogenetic importance in this family, as noted in general by Lang (1948), since it has been recorded in completely unrelated taxa (Karanovic 2004).

Parastenocaris kimberleyensis belongs to the *"brevipes"*-group of species (having the characteristic endopodal complex of the male fourth leg; the long distally serrate endopod of the female fourth leg; the tapering caudal ramus with dorsal and lateral setae inserted around midlength; the sixth legs in male fused into a single operculum; and the bilobate fifth leg in female), which was defined by Lang (1948) and named after the type species of the genus. Most recently Galassi and De Laurentiis (2004) proposed "retaining within *Parastenocaris* only those species belonging to the *brevipes*-group (as revised by Reid 1995), and to relegate the remainder presently assigned to this genus as *Parastenocaris s.l.*, pending the revision of the family". I prefer to wait for that revision instead of using *sensu stricto* and *sensu lato* terms, because they provide no real advancement to our knowledge on this complex taxon. Besides *P. brevipes*, which is the only member of the genus with a Holarctic distribution (see Lang 1948; Reid 1995), 16 species have been described so far in the *"brevipes"*-group: five of them from Sri Lanka by Enckell (1970) [*P. brincki, P. irenae, P. lanceolata, P. noodti* and *P. singhalensis*]; four from the United States by Pennak (1939), Borutzky (1952), Whitman (1984) and Reid (1991) [*P. starretti, P. wilsoni, P. texana* and *P. palmerae* respectively]; three from Japan by Miura (1962, 1969) and Kikuchi (1970) [*P. oshimaensis, P. biwae* and *P. hinumaensis* respectively]; two from India by Ranga Reddy (2001) [*P. gayatri* and *P. savita*]; one from China by Shen and Tai (1973) [*P. longipoda*]; and one from Sumatra by Chappuis (1931) [*P. feuerborni*]. *Parastenocaris biwae, P. starretti* and *P. wilsoni* were consequently synonymized with *P. brevipes* by Reid (1995), who also recognized "the possible origin of the *brevipes-* group in tropical Asia". *Parastenocaris texana*, because of the incomplete original description, should be placed as *incertae sedis* until a proper redescription of the type material is presented. Reid (1995) expressed doubts about the position of her *P. palmerae* in the *"brevipes"*-group, but there are currently no strong reasons to exclude this species. Galassi and De Laurentiis (2004) also included *P. longicaudis* Chappuis, 1931 and *P. arctica* Bortutzky, 1952 in this group, although they are known only as females and their statuses could not be verified (see Lang 1948; Borutzky 1952). Together with *P. kimberleyensis* 14 valid species could be recognized today in the *"brevipes"*-group, and a key to aid in their difficult determination is given below (based solely on the morphology of males, since females of *P. brincki, P. lanceolata* and *P. singhalensis* are still unknown).

Key to the "brevipes"-group of *Parastenocaris*

1. Third leg in adult male without endopod 9
–   Same appendage with endopod 2

2. Third leg endopod reduced to single slender seta 4
–   Third leg endopod small but distinct segment. 3

3. Fourth leg endopod with transverse subapical row of 3 long spinules .... *P. feuerborni* Chappuis, 1931
–   Same segment with longitudinal row of 5–6 long setules .... *P. kimberleyensis* sp. nov.

4. Fifth leg with inner-distal corner produced posteriorly as spiniform process 5
–   Same appendage lacking spiniform process .. 6

5. Fifth leg with only 2 setae ....*P. brincki* Enckell, 1970
–   Same leg armed with 4 setae .... *P. palmerae* Reid, 1991

6. Fourth leg endopod 2-segmented, with 2 apical spinules 7
–   Same ramus 1-segmented, with more than 2 spinules 8

7. Third leg first exopodal segment without subapical spine .... *P. longipoda* Shen and Tai, 1973
–   Same segment with well developed outer spine apically .... *P. savita* Ranga Reddy, 2001

8. Third leg first exopodal segment armed with large dentate process on inner margin .... *P. gayatri* Ranga Reddy, 2001
–   Same segment with smooth inner margin .... *P. brevipes* Kessler, 1913

9. Anal operculum smooth 11
–   Anal operculum with row of spinules 10

10. Male fourth leg endopod conical and smooth.. .... *P. oshimaensis* Miura, 1962
–   Same ramus sickle-shaped, with 1 long spinule .... *P. hinumaensis* Kikuchi, 1970

11. Fifth leg inner-distal corner produced posteriorly as spiniform process .... *P. irenae* Enckell, 1970

In his revision of the family Parastenocarididae, Jakobi (1972) divided this group of species into five separate genera (all, except the first one, described as new): *Parastenocaris, Oshimaensicaris, Biwaecaris, Enckellcaris* and *Brinckicaris*. The superficial nature of this revision is highlighted by the fact that the type species of his genus *Biwaecaris* is synonymous with the type species of *Parastenocaris* (see Reid 1995). Although it is generally accepted that some of the species groups within *Parastenocaris* will be elevated to the generic level (Enckell 1970; Schminke 1976; Por and Hadel 1986; Reid 1994; Cottarelli *et al.* 1995; Martinez Arbizu 1997; Galassi and De Laurentiis 2004) it is currently untenable to base such a revision solely on morphology. Numerous convergences are normally expected in genera that have invaded freshwater habitats during or before the Pangaean era and partly (or completely?) already stygomorphic (from the marine psammon). However, the *"brevipes"*-group is one of the best defined and most compact groups and, since it contains the type species the generic name of *Parastenocaris* will probably persist for a long time. Galassi and De Laurentiis (2004) even defined the members of this group as *Parastenocaris s.s.* and provided an overview of all major important morphological characters. Their ecological niche is generally very close to the surface (*P. brevipes* in Europe even inhabits *Sphagnum* bogs), which enables them to grow bigger than other members of the genus, reaching usually 0.5 or 0.6 mm. The main reason for this is probably the bigger sand particle size near the surface (a consequence of natural process of sedimentation), but a more abundant food imput may be responsible as well. The presence of this group in northern part of Australia may suggest their relatively recent arrival, if the hypothesis of the origin of this group in tropical Asia is correct (Reid 1995). But, in order to arrive at more reliable zoogeographic conclusions a lot more work is required on the taxonomy, ecology and ethology of this group.

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